APPENDIX A

LETTER REVIEWING AND CRITIQUING THE PHYSICAL PROCESSES CONTROLLING THE TRANSPORT AND MIXING OF HEATED DISCHARGES FROM THE CHALK POINT STATION OF THE POTOMAC ELECTRIC POWER COMPANY.

By

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December 5, 1984

Dr. Fred H. Holland
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Dear Fred:

Enclosed are our reviews of Chapter III-B and Chapter IV of "Chalk Point Station, 316 Demonstration-Technical Reports" (Attachment (1)) and the report entitled "Analysis of 1983 Dye Studies at Chalk Point Power Plant and Comparison to Model Results" (Attachment (2)). They are based on our analysis of the two reports, the supplementary documents furnished in your letter of 10 September 1984, and the archived literature.

With respect to the question contained in the letter from Robert L. Dwyer addressed to Prof. Harry Carter, dated 16 November 1984, which asked that we provide our "best professional judgement concerning whether the plant passes each of the four criteria at 660 MWe", it is our opinion that the data analysis and model result interpretations presented in the reports we were asked to review do not provide a clear cut answer to this question. However, a partial answer is provided by our reanalysis of some of the data and our reinterpretation of some of the results given in these reports. Specifically, our reanalysis of the 1983 dye study data for the plant intake and discharge gives a first order estimate of the effective dilution flow at the plant site of 108.5 m^3/sec. For full power production of 660 MWe, with a condenser flow rate of 31.4 m^3/sec, the tidal mean sectionally averaged excess temperature would be 2.4°C, and the condenser flow rate would be 29% of the tidal mean effective dilution flow. A reinterpretation of the results of the laterally averaged model gives similar results, indicating that the tidal mean sectionally averaged excess temperature at a cross-section near the discharge, for full power production would be 2.2°C, corresponding to an effective dilution flow at that location of 116 m^3/sec. These same model results, when properly interpreted, indicate that more than 80% of the cross-sectional area at this location would have excess temperatures greater than 2°C.

We have also made an independent first order (i.e., rather rough) analysis of the salinity data collected by ANSP during the period May 1976 through September 1979, and used these data in a simple one-dimensional mixing ratio model of the Patuxent estuary. This model is based on simple

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basic principles of estuarine kinematics. While this model does not provide information on the detailed distribution of an introduced pollutant, such as excess heat, it does provide a first order estimate of the effective tidal mean dilution volume for any cross-section within the estuary. Our use of this model gives 104 m^3/sec for the tidal mean effective dilution flow at river mile 22, At the full power production rate of 660 MWe, with a condenser flow rate of 31.4 m^3/sec, this effective dilution flow corresponds to a tidal mean sectionally averaged excess temperature of 2.48 ^oC. The condenser flow rate in this case represents 30% of the available tidal mean dilution flow rate.

Although knowing the sectionally averaged excess temperature does not in itself provide information as to the fraction of the cross-section which has excess temperatures above 2^{o}C, examination of the observed distribution of excess temperature near the plant suggests that if the sectionally averaged excess temperature exceeds 2.0^{o}C, then more than 50% of the cross-section has excess temperatures greater than 2.0^{o}C. Thus all three of these analyses indicate that the plant would fail to meet Regulations 10.50.01.13.E (1)(a) and (c). These analyses do not provide information as to whether or not the plant would pass Regulations 10.50.01.13.E (1)(b) and (d).

These conclusions are about the same as those which can be arrived at from a reanalysis of earlier studies; for example, the dye studies reported by Pritchard and Carter (1965), Carter (1968), and the kinematic model analysis made by Pritchard (1969). These studies additionally suggest that the distribution of excess temperature under full load would probably result in the plant failing to meet Regulation 10.50.01.13.E (1)(b).

It is our opinion that the annual average available tidal mean effective dilution flow at the plant site is in the range 100 m^3/sec to 120 m^3/sec, and that its average over, say, a 5 day period, does not vary significantly outside this range with season. This means that the most probable value of the critical sectional mean excess temperature near the plant site would fall in the range from 2.16^{o}C to 2.59^{o}C, and, based on the observed distribution of relative excess temperature in the cross-sections near the discharge, the critical cross-section would have excess temperatures exceeding 2.0^{o}C over 60% to 80% of the cross-sectional area. Thus, we consider it to be a clear cut call that the plant would fail to pass Regulations 10.50.01.13.E (1)(a) and (c). We are less certain that the plant would fail Regulation 10.50.01.13.E (1)(b) with respect to the 24 hour average length of the 2.0^o excess temperature isotherm, but think it is likely. The evidence is not clear cut with respect to the extent of the bottom area which would be subject to excess temperatures greater than 2.0^{o}C.

From the standpoint of the State Regulations, the Chalk Point Plant is too large for the site. If the plant had been located a few miles down the estuary, say at River Mile 18 or 19, our exercise of the mixing ratio kinematic model, using the ANSP set of observed salinity distributions, indicates that all of the State Regulations for thermal discharge could have been met, particularly with a properly designed intake and discharge arrangement. Whether the probable failures of the plant as it exists to meet State regulations represent gross failures is a matter of opinion. Although you did not ask for our opinion concerning the probable environmental consequences of allowing the plant to operate at full load despite its failure to meet certain thermal regulations, we are of the opinion that it does not necessarily follow that failure to meet these arbitrarily established critical areas constitutes an adverse impact on the biota of the Patuxent Estuary. Of much greater concern, and one which does not appear to have been addressed in any of the reports we were asked to review, is the discharge of chlorine and of heavy metals, particularly of copper.

Listed below are the references which we have referred to in the text of this letter.

Pritchard, D.W. and H.H. Carter. 1965. On the prediction of the distribution of excess temperature from a heated discharge in an estuary. Chesapeake Bay Institute, The Johns Hopkins University, Tech. Rept. 33, Ref. 65-1, 45 pp.

Carter, H.H. 1968. The distribution of excess temperature from a heated discharge in an estuary. Chesapeake Bay Institute, The Johns Hopkins University, Tech. Rept. 44, Ref. 68-14, 39 pp.

Pritchard, D.W. 1969. Appendix D. In: Nuclear Power plants in Maryland. Governor's task force on nuclear power plants, Annapolis, Maryland.

Very truly yours,

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Consultant

Harry H. Carter
Consultant

DWP:HHC:eg
Attachments (2)

Attachment (1) December 5, 1984

Comments on Chapter III-B and Chapter IV of "Chalk Point Station, 316 Demonstration - Technical Reports".

Introduction

These chapters deal with estuarine hydrodynamics of the Patuxent with respect to the Chalk Point discharge and with numerical modeling of: (a) the estuarine hydrodynamics, (b) the dilution of the plant discharge, and (c) the temperature distribution in the thermal plume.

Summary of Conclusions

We can summarize our general conclusions regarding this report briefly as follows:

(a) The statements and discussions given in this report concerning estuarine behavior are conceptually correct. They indicate that the author(s) recognize the inherent complexity of estuarine motion, and the interaction of density drive flow and nonlinear tidal driven net flow.

(b) The laterally averaged two-dimensional model used for computations described in this report is near to state-of-the-art in estuarine modeling.

(c) The vertically averaged two-dimensional model used in computations described in this report is not of the same level of technical excellence as is the laterally averaged model. In fact, this vertically averaged model is suspect due to the neglect of several possibly important terms in the basic equations of motion.

(d) The manner of use of these tools (the models) in this particular implementation involves certain factors which may adversely affect the validity of the results given in this report.

(e) Thus our problems with this report are not with the basic concepts as stated in the text, but rather with the implementation of these concepts.

Our more specific comments and conclusions are:

(f) The laterally averaged model should have been exercised as a real time model, with the actual time variations in water surface level and salinity at the mouth of the Patuxent driving the model. The model then should have been verified by comparing the computed temporal and spatial variations in the salinity distribution with the observed distributions as obtained by ANSP during the simulated period.

(g) As actually implemented, there is insufficient verification of the laterally averaged model to assure that the computed excess temperatures are "correct" to the accuracy required for a determination of whether or not the plant meets certain of the Maryland regulations.

(h) Even accepting the results of the laterally averaged model at face value, these results have been incorrectly interpreted with regard to sectional mean temperatures and dilution flows. When interpreted correctly, the results of the laterally averaged model, which is certainly the nearest to state-of-the-art technology which has been applied to this problem, indicates that the Chalk Point plant fails to meet the Maryland regulations.

(i) The basic vertically averaged equations of motion simulated by the vertically averaged numerical model used in this report are deficient in that several terms are omitted which are likely to be important for the situation considered here.

(j) This abbreviated vertically averaged model was driven at its up estuary and downestuary boundaries by velocity data not collected at these boundary locations. Even if the complete vertically averaged equations had been simulated, the failure to drive the model with data applicable to the boundaries would negate any confidence which could be placed in the results.

(k) An inadequate data set was used in an attempt to verify this model. Even though the data used in this verification attempt represented parameters which should be best simulated by the model as formulated, the model failed to adequately reproduce these data.

(l) Finally, for all the reasons summarized above, the data and analysis presented in this report are inadequate to demonstrate that the Chalk Point Power Plant would, at full load, be in compliance with the thermal regulations of the State of Maryland.

Specific Comments

Estuaries are water bodies within which fresh water derived from land drainage is mixed with salt water derived from the ocean. The salt water moves into the estuarine system and the mixed water is discharged out of the estuarine system by the combined effects of density driven circulation, non-linear tidal induced flows, and meteorological forced motions, both near field and far field. On the basis of the descriptive text, we conclude that the author(s) of this report recognize(s) this complex combination of driving processes in estuarine motion and exchange.

The report describes a near state-of-the-art laterally averaged two-dimensional numerical model of hydrodynamics of the Patuxent estuary. The model is driven by the tidal rise and fall of the water surface at the mouth of the estuary, by the fresh water entering the head of the estuary, and by the internal pressure field produced by the distribution of density. The model is capable of also having as input the wind blowing over the surface of the estuary, but this feature was apparently not used in the simulations carried out for the Patuxent. The density distribution is computed, using a simplified equation of state, from the distribution of salinity. The salinity at the mouth of the estuary is given as an input, and the salinity at the head of the estuary is taken to be zero and held constant at this value. The velocity field computed by the hydrodynamic model at each time step is used in a water quality submodel which computes the internal distribution of salinity. The salinity is then fed back via the equation of state and the density field to compute the internal pressure driving term.

There are several disappointments with the use of this model for the Patuxent in this report. Only the M_2 tidal component is used to drive the model at the mouth in an examination of a pseudo "stationary state", which was intended to be similar to the conditions which occurred during the 19 July to 8 August 1978 period of the ANSP velocity surveys. These velocity data (Polgar et al., 1980) show that the subtidal motions in the Patuxent during this period were significantly influenced by barotropic motions apparently driven by water surface variations at the mouth, which were in turn produced by wind events over the Bay or over the adjacent continental shelf. Thus the decision to simulate this period as "stationary state" does not appear to us to be a satisfactory decision. The model should have been driven with the real variation in sea level at the mouth. The inclusion of the wind stress term on the surface of the estuarine model would also have been desirable.

If the model had been run as a "real time" model, then one very good verification of the combined hydrodynamic-water quality model would be to compare the computed salinity distributions with the observed vertical and longitudinal salinity distributions measured by ANSP during the simulated period. As it is, the best one can say is that the computed vertical/longitudinal distributions of laterally averaged currents, salinities and temperatures appear to be reasonable simulations. There is insufficient verification of the model to assure that the computed excess temperatures are "correct" to the accuracy required for a determination of whether or not the plant meets certain of the Maryland regulations. The problem is that on the face of it, using crude first order approximations of the dilution water available at the plant site based on the average longitudinal salinity distribution along the length of the Patuxent, there is only a marginal probability that the dilution requirements can be met. Therefore, the more sophisticated modeling of the system, which unlike the crude 1st order model includes adjustable parameters which are not a priori determined by the physics, requires careful verification to assure that these several coefficients have been set to values appropriate to this particular estuary.

The above is not intended to imply that we have any basis for saying that the model results are wrong. We simply say that the confidence which can be placed on the results depends upon how well the model has been verified against real data. The limited verification using tidal range and phase is not sufficient to assure that the subtidal flow pattern, which is a major controlling factor in the distribution of salinity and temperature, is sufficiently well simulated. Consequently, we have no confidence that the modeled laterally averaged excess temperature distribution is correct.

However, even taking the model results on face value, these results are misrepresented in statements made in the text relative to sectional mean excess temperatures and dilution flows. For example, on page 123, 2nd paragraph, the following statement appears: "The vertically-averaged excess temperature at the discharge (from Table III-B.2-9) is 1.85°C, and is equivalent to a dilution flow of 139 m^3/sec for a 660 MWe heat rejection rate of 259°C x m^3/sec." The referenced table in this sentence contains the laterally averaged excess temperature values for 1-m depth intervals at various sections along the length of the Patuxent, as computed by the model. The values in this table have also been averaged over the tide, which tends to reduce peak values which would occur at somewhat different positions at various stages of the tide, thus smoothing the longitudinal distribution. Be that as it may, the major problem here is that a simple average over depth of these laterally averaged excess temperature values was taken. The implication is made, based on the use of this average to compute dilution, that this average is a sectional average mean excess temperature. The correct sectional average is obtained by weighting the value for each 1-meter depth interval by the width of the cross-section for that depth. Using the estuarine width data given in Table III-B.2-7, we have made an estimate (we could not exactly match up the width data with the location of the section used in the computations) of the sectional mean temperature at the discharge. The result is 2.2°C, not 1.85°C as given in the report, and the effective dilution flow is 116 m^3/sec, not the stated 139 m^3/sec. The ratio of this dilution flow to consenser pumping rate is then 3.7, not 4.6 as stated in the report. The ratio of the dilution flow to the total pumping rate (including auxiliary pumps) is 2.6. Thus, on the face of it, the results of this laterally averaged model, which is certainly the nearest to state-of-the-art technology which has been applied to this problem, indicates that the Chalk Point plant fails to meet the Maryland regulations.

The two-dimensional hydrodynamic transport model used in simulating the horizontal distribution of vertically averaged excess temperature raises much more serious questions than does the laterally averaged model. First of all, the basic vertically averaged equations of motion given on page 322 as Equations (1) and (2), are incomplete. While in many hydrodynamic problems one or more terms of the equation of motion can be considered small and hence neglected, the terms omitted from the equations of motion appear to us to be very important in this problem. The distribution of properties, such as temperature, depends not only on the first order, or linear, tidal hydraulics, but also on the subtidal circulation driven by the density distribution and by the nonlinear tidal terms. Certainly the lateral distribution of the velocity field is important in the distribution of excess temperature from a shoreline discharge, and the Coriolis term, coupled with the density distribution, contributes to lateral variations in the velocity field. Equations (1) and (2) on page 322 of the subject report do not include the nonlinear field acceleration terms, the Coriolis term, or the internal pressure force term produced by a horizontal gradient in density.

We anticipate that the author(s) would argue that these missing terms are accounted for by driving the model with a set of vertically averaged observed velocity data at the downestuary and upestuary boundaries of segment of the waterway being modeled. We do not concur that this is a valid argument. Also, the lower boundary is at Long Point, but the only set of observed velocities at that location were abandoned. Instead "The values at Benedict were moved to Long Point since the Long Point measurements in Table IV-2 were not representative of conditions during the more complete record". We question this decision. An inspection of these velocity data sets suggests to us that the data set at Long Point is characteristic of estuarine circulation. The data sets for Benedict and for Chalk Point obtained during July and August 1978 appear to us to represent either an anomolous time series (that is, resulting from an unusual combination of far field and near field meteorological forcing conditions), or a rather unique responses to local geometry. The transfer of the data set from Benedict to another geometric environment at Long Point is a very likely source of considerable error in the model results even if the equations used to formulate the model had been complete.

In view of the fact that the measured velocity data at Benedict were transfered to Long Point and used as input to the seaward boundary of the model, and that the observed velocity data from Trueman Point were transfered to Holland Cliff and used as input to the upestuary boundary of the model, the comparison of computed vs observed maximum flood velocities for several locations in the cross-sections at Trueman Point, Chalk Point, and Benedict are certainly unimpressive. The Chalk Point data set is the only one which can be considered as driven by the dynamics of the model but not directly dependent on the boundary input. A simple linear regression of the observed vs computed values of maximum flood and maximum ebb velocities for this station give a coefficient of determination, r^2, of 0.410. That is, only 41% of the variance in the observed ebb and flood velocities can be explained by the model results. The complete data set, including the data from Trueman Point and Benedict, gives an $r^2 = 0.537$.

The maximum ebb and maximum flood velocities, however, are parameters which should be best simulated by the model as formulated. A much more critical test would be to compare the computed and observed subtidal velocity distributions.

A final point with respect to this model concerns the question of what boundary values were used for dye and excess temperature at the two open boundaries. That is, what were the "upwind" values used for the most downestuary cells during flood current and for the most upestuary cells during ebb current? Certainly there is some feedback of dye and excess heat from downestuary and from upestuary into the modeled reach of the waterway. The report does not include information as to how this boundary condition was handled, and so we cannot judge whether or not the procedures followed were unbiased. If the model failed to include any provision for simulating a feedback of excess heat from downestuary and upestuary areas into the modeled reach of the estuary, the computed excess temperatures in this reach would represent an underestimation of the actual excess temperature.

Reference

Polgar, T.T., R.N. Ross and Gail K. Lacey. 1980. Analysis of Patuxent estuarine currents in the vicinity of the Chalk Point Steam Electric Station. Maryland Power Plant Siting Program, PPSP-CP-80-3.

Attachment (2) December 5, 1984

Comments on the report entitled "Analysis of 1983 Dye Studies at Chalk Point Power Plant and Comparison to Model Results." J.E. Edinger and E.M. Buchak. 30 March 1984 (revised 29 June 1984).

Introduction

This report describes and analyzes the results of the 1983 dye study conducted at the Potomac Electric Power Company Chalk Point Power Plant between 6 and 21 December 1983. The study results were used to determine the spatial and temporal distribution of excess temperatures for an average plant load of 573.3 MWe which existed during the study and which were then extrapolated to full power (660 MWe) for comparison of the 24-hour average plume to modeling values and the State of Maryland plume regulations.

Summary of Conclusions

We can summarize our conclusions regarding this report as follows:

(a) There was apparently vertical and/or lateral structure in the field of background temperature of $\sim$ 2-3°C during the dye study (Figs. 5.1.a. through 5.11.a. except for Fig. 5.4.a.). As a result, only an average of 53% of the temperature variance could be ascribed to the plant through the regressions of temperature on dye concentration. Since these regressions form the basis for estimating background temperatures, errors in their estimation will be reflected in all analyses that follow.

(b) In Table 4.1 of the report, which provides conditions and certain environmental and plant parameters during each dye-temperature survey, the listed ambient temperatures are higher than the intake temperatures on 7 of 10 days. Since the intake temperatures include an effect of recirculation, the listed ambient temperatures are suspected of being too high unless the background temperatures in the entrance to Swanson Creek, where the plant intake is located, were substantially cooler during the survey than in the estuary proper. We have no reason to believe this is the case.

(c) Our reestimates of the ambient temperatures based on measured recirculation values from the discharge and intake dye concentrations and the measured intake and discharge temperatures leads us to believe the ambient temperatures listed in Table 4.1 are too high by about 1.5°C on the average. Taking this into account (Table 2 in this enclosure), leads to the conclusion that the tabulated fully mixed excess temperatures are too low by 19% and the tabulated dilution ratios are too high by the same factor. Thus we estimate the average dilution flow during the experiment to be 108.5 m^3s^{-1} at the plant site vice the value listed in the report of 148.5 m^3s^{-1}. At full power, therefore, the condenser flow of 31.4 m^3s^{-1} is 29% of the dilution flow which exceeds Regulation 10.50.01.13.E (1)(a) by 45%.

(d) The report states that the largest percentage of water greater than 2°C in a cross-section was found to be 37.5% at Section 8 after scaling up to full power. The regression used for scaling plume length and percent cross-section to full power suggests that plant load and cross-section are only slightly related and plume length and plant load only moderately related. Fig. 5.6 of the report shows the resulting cross-sectionally tidally averaged excess temperatures at 660 MWe. If these temperatures are increased by 1.5°C (our estimate of the errors in background temperature) over 95% of the section will contain temperatures greater than 2°C which violates Regulation 10.50.01.13.E(1)(c).

(e) Chapter 6 of the report compares the excess temperature distributions derived from the 1983 dye study scaled to 660 MWe with the longitudinal-vertical model results (laterally averaged) and with the vertically integrated model predictions. Our comments relative to these models are contained in our analysis of the 316 demonstration and will not be repeated here. The excess temperature distributions derived from the 1983 dye study, however, are suspect for the reasons stated above, namely, poor scaling correlations between plant load and plume length and plant load and percent cross-section greater than 2°C, and possible overestimates of background temperature due to the lateral and vertical variations in background temperature at the time of the dye study. As a result, we feel the comparisons of model results with dye computed temperatures in their present form are meaningless.

The 1983 Field Study

The dye study portion appears to us to have been competently carried out. We would have preferred, however, that the dye pumping rate matched the plant load, i.e., the temperature rise across the condensers. This is highly desirable, if not necessary, if the excess temperature is to be correlated with dye concentrations for the purpose of estimating the background temperatures. The sampling scheme, which consisted of sampling over several hours centered at slack water, might have missed peak concentrations at some locations within a tidal excursion of the discharge since they are produced at slack water at the discharge and then advected up and downestuary. The report contained no statement regarding background variations in fluorescence. We note that the plant was not chlorinating thus eliminating a potentially serious source of error in the results. No compensation to the dye measurements for photochemical decay was attempted but, compensation is not possible without knowledge of the dye's age (time since injection) at all points in the estuary. In addition, and more importantly, we do not believe this is an important source of error. On balance, we feel the dye measurements were made carefully and are sufficiently accurate to quantitate the processes producing dilution of the plant's discharge of water. However, the matter of scaling these dye concentration measurements to excess heat or temperature raises certain questions which will be addressed at some length later on.

The current meter data as shown in Figs. A.1-A.11 seems to suggest some mean flows that are opposite to those shown in Tables 2.3-5 for the same meters. For example, at Holland Cliffs Table 2.3 shows positive values at the surface (width = 0.4) whereas Fig. A.1 shows a negative mean velocity. A similar anomaly is apparent by comparing the results for Holland Cliffs at the surface and width 0.4 with Fig. A.1. Table 1 below summarizes the more obvious inconsistencies noted for Holland Cliffs. Is it possible that the current meter results, which were used to drive the model, were misapplied or do the anomalies merely represent careless writing? In addition, the computed tidal harmonics shown in Figs. A.1-A.11 are not good representations of the data for days 338, 342, and 347. See all Figs. for days 338, 342, and 347.

Table 1

Comparison of Tables 2.3-5 with Figs. A.1-A.4

Surface Currents @ Holland Cliffs

	0.4	0.7	0.8
338-342	+/-	+/?	+/?
343-347	+/-	-/+	-/+
348-352	+/-	+/?	+/?

Bottom Currents @ Holland Cliffs

	0.5	0.7
338-342	+/-	+/no data shown
343-347	-/+	-/no data shown
348-352	+/-	+/no data shown

Key: Table 2.3-5/Figs. A.1-A.4

With respect to the temperature and salinity data collected, we would have liked to have seen the data plotted as longitudinal and lateral cross-sections vice 2 tables (Tables 2.1 and 2.2) depicting typical SBE and SBF condition so that we could better evaluate the suitability of using the intake dye concentrations as estimates of the cross-sectional mean dye concentration at the intake (p. 3.3, 2nd para.) and of the volumetric mean dye concentration of the section between Holland Cliff and Long Point (p. 3.3, 3rd para.).

Estimates of Dilution from Intake Dye Concentrations

On page 3.3, an estimate of the estuarine dilution flow is made by comparing the 4.7 ppb increase between intake and discharge to the 0.8 ppb at the intake. This suggests that the recirculation can be used as a measure of dilution from the following formula

$$\text{dilution} = \frac{1\text{-recirc}}{\text{recirc}}$$

This is only true, however, if the intake concentration is a good estimate of the fully mixed or cross-sectional mean dye concentration at the intake section. If lower than the cross-sectional mean, it will overestimate dilution flows.

The use of equation 3.1 to estimate dilution flows from dieaway at the intake is also somewhat suspect. The answer one gets is critically dependent upon the values used for $C(t)$ and C_o. They should be volume averages of the section between Holland Cliff and Long Point, not just intake values. We cannot determine the sign or amount of the error introduced by using intake concentrations vice volumetric averages with the data available to us.

Analysis of the Plume Survey Data

These data were analyzed by regressing the temperature measurements on dye concentrations using all stations and depths in the near field region. The resulting regression provides an estimate of the average temperature, $\bar{T}_n$, of the volume of diluting water into which a unit volume of heated effluent is mixed. In the case where the receiving waters are isothermal (background temperature, T_b, is constant), $\bar{T}_n$ equals T_b (Carter et al. 1975). In carrying out these regressions it does not appear that the discharge dye concentrations and temperatures were used. The regressions should have been made to pass through these points since they are easily measured and, because there are no dye or heat loss problems to deal with, they are the most accurate comparisons of dye concentration and excess temperature that can be made. Without seeing the data, however, an estimate of their effect on the regressions cannot be made.

All, except one regression (Julian day 350 SBE), indicate that there is vertical (or lateral) structure in the background temperature field (Figs. B.1.a–B.11.a) and that the regression provides estimates of $\bar{T}_n$, not the true background temperature at all locations in the near field. As a result, the slopes are incorrect; low where the background temperatures are colder than $\bar{T}_n$ and high where they are warmer. Since the slopes are used as scaling factors for converting dye to temperature, errors are introduced into these estimates. We can make some worst case estimates of this effect from the information in Table 4.1 as follows.

Let r be the recirculation given by

$$r = \frac{C_{int}}{C_{dis}} = \frac{T_{int}-T_b}{T_{dis}-T_b} \quad (1)$$

Rearranging eq. (1), we have

$$T_b = \frac{T_{int} - rT_{dis}}{1-r} \quad (2)$$

New estimates of T_b from equations (1) and (2) using the dye concentrations at the intake and discharge and the intake and discharge temperatures in Table 4.1 are tabulated in Table 2, below. We first note that in 7 of the 10 cases listed in Table 4.1, the intake temperature was lower than the estimated ambient temperature. This does not produce a high degree of confidence in the values of ambient temperature, T_b, tabulated in Table 4.1.

Table 2

Julian Day	T_{dis}	T_{int}	New T_b,est. Eq. (2)	$\bar{T}_n$ or T_b,tab	$T_{dis}-\bar{T}_n$	$T_{dis}-T_b$(new)	Scale Factor Increase
345	14.6	6.9	5.55	7.37	7.23	9.05	1.25
346	17.4	8.0	6.52	7.59	9.81	10.88	1.11
349	14.9	8.1	7.20	8.31	6.59	7.70	1.17
350	17.0	8.1	7.01	7.74	9.26	9.99	1.08
351	16.7	7.8	6.64	7.64	9.06	10.06	1.11
352	14.3	5.9	5.00	6.81	7.49	9.30	1.24
352	16.0	7.2	5.90	7.76	8.24	10.10	1.23
355	11.6	3.3	1.96	4.35	7.25	9.64	1.33
						average =	1.19

The appropriate regression equation is from Carter et al. (1975)

$$T(x,y,z,t) = \frac{C(x,y,z,t)}{C_{dis}} (T_{dis}-\bar{T}_n) + \bar{T}_n \qquad (3)$$

The slope, or scaling factor of the dye measurements can now be adjusted by the factor $(T_{dis}-\bar{T}_n)/(T_{dis}-T_b)$. The average of these factors is 1.19. The values of the fully mixed excess temperatures and the dilution ratios in Table 4.1 should now be adjusted upward and downward, respectively, by this factor; they are in error by 19%. 2 of the 12 values of the fully mixed excess temperature now exceed 2°C. One thing that stands out in connection with Table 4.1 is that the regression with the highest correlation coefficient (Julian day 350) provided the lowest dilution and highest fully mixed excess temperature.

We suggest that the field of excess temperature also be estimated from the measured temperatures by scaling them to excess temperature by subtracting $\bar{T}_n$ (the intercept in the region). The result is two separate realizations of the field of excess temperature, one based on measured dye concentrations scaled by the regression slope and one based on measured temperatures and the regression intercept. A comparison of these two sets of estimates might prove useful.

We note on p. 4.5 that plume length and % cross section were scaled to full load by two relationships with coefficients of determination (R^2) of 0.19 and 0.30, respectively. This does not inspire confidence in their projection to full load.

The first full paragraph on page 5-2, reads as follows: "The longitudinal-vertical distribution of excess temperatures gives an indication of the overall dilution taking place near the discharge. At the discharge, Section 8, the vertically averaged excess temperature is 1.41°C. The plant temperature rise at 660 MWe is 9.3°C. Therefore, the discharge must be diluted 5.54 times within the discharge section. This is an equivalent dilution flow of 131 m^3s^{-1}." The author has made the same mistake here that he did in the 1983 ANSP report, in that a simple vertical mean of the laterally averaged excess temperatures is not the correct average to use in computing dilution flows. The proper mean to use is the sectional average excess temperature, which is obtained by weighting the values at each depth by the width of the cross-section. This results in a greater weight for near surface values, and hence a larger mean excess temperature. The equivalent dilution flow would then be lower than that given.

Model Results

The model results given in this report are the same as those given in the Chalk Point Station, 316 Demonstration-Technical Reports, Volume 1, September 1983, ANSP. The comments we made with respect to these in our review of that report also apply here.

Reference

Carter, H.H., D.W. Pritchard, and S.R. Rives. 1975. The analysis and interpretation of a heated jet. Paper presented Civil Engineering in the Oceans/III, CBI Contr. 222, SUNY Contr. 134. .pa

DONALD W. PRITCHARD
23 Harbor Hills Drive
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(516) 331-2681

December 5, 1984

Dr. Robert L. Dwyer
Martin Marietta Environmental Systems
9200 Rumsey Road
Columbia, MD 21045-1934

Dear Bob:

Reference is made to your letter of 16 November requesting our opinion on two questions which were not incorporated into our reviews forwarded on 5 December 1984. In order to avoid repeating the full text of your questions here, we have attached hereto a copy of the second page of your letter of 16 November.

We first point out that we consider these questions somewhat moot since we do not consider that either model was adequately calibrated or verified in any case. However, your questions include some general concerns about the use of models which warrent comment. First, it should be pointed out that a primary use of models is for prediction under conditions for which data is not available. If a complete set of data were available for the desired situation there would be no need for the model.

In this paragraph we will consider a hydrodynamic model which is properly formulated, and includes all the terms pertinent to the range of conditions for which the model is to be applied. Then if this model is carefully calibrated for one set of conditions and verified for another set, the model should produce valid predictions for conditions outside the range over which calibration and verification occurred. As a case in point the Army Corps of Engineers hydraulic model of the Chesapeake Bay was adjusted to reproduce the tidal and density driven flows under the normal range of fresh water inflows, and to adequately simulate the longitudinal and vertical distribution of salinity under these conditions. Later the model was run to simulate the extraordinary fresh water inflow conditions which occurred during tropical storm Agnes. These conditions were so far outside the expected range of fresh water inflow to the Bay that the water supply to the model had not been designed to provide such flows and temporary connection to the fire hydrant supply had to be made. Even so, the model simulated the time varying longitudinal and vertical distribution of salinity which had been observed in the Bay in the several month period following Agnes quite well. A predecessor to the two-dimensional laterally averaged model used in the Patuxent has been very successfully used in large reservoirs to predict the distribution of temperature and dissolved oxygen under conditions outside the range of conditions for which the model had been adjusted.

The problems we have in the case of the model studies under review are the following:

(a) The laterally averaged two-dimesional model, which is the only model used in these studies which was properly formulated, was not run in a mode which would allow us to determine if the parameters controlling vertical mixing were properly adjusted. That is, the model was not adequately verified against the ANSP set of temperature and salinity observations made during the period May 1976 through September 1978. Verification against this data set would have provided evidence whether or not this model was adequately adjusted so as to simulate the time varying longitudinal and vertical distributions of salinity, and hence of stratification, under a time varying fresh water input. As it is, we cannot place any degree of confidence that the predictions of this model for the winter conditions of high flow (and hence high stratification) are valid. If however, the model had been well verified for a reasonable range of conditions, then we believe this model is well enough formulated to provide reasonably valid predictions of the longitudinal and vertical distributions of the laterally averaged excess temperature for river flow conditions outside the range used for verification.

(b) It is our opinion that the vertical integrated model suffers from such fatal flows that no amount of adjustment to a given set of conditions could warrant any confidence in model results for conditions outside of the range of those used for adjustment. In fact, as used in the Patuxent, we do not believe that the model could be adjusted to reproduce the longitudinal and lateral distributions of current velocity, and consequently of excess temperature, even for the period over which the adjustment was being made. This is borne out by the fact that the model failed to even adequately duplicate the observed lateral distribution of maximum flood and ebb velocities within the modeled reach which should be among the easiest parameters for such a model to simulate. We do not agree that this model was adequately calibrated and validated using the field thermal and dye studies for any power load condition, and in fact we do not believe that such a calibration and validation of this model could be made. Hence the question as to whether the model could be used to predict the dimensions of a full power plume is moot. We do not believe that this model as formulated could predict the dimensions of the thermal plume under any set of conditions.

Suppose that a properly formulated vertically averaged model were to be applied to the Patuxent, and that such a model were to be adequately calibrated and verified for some reasonable range of forcing conditions. Could then such a model be used to predict the distribution of, say, the vertically averaged excess temperature under river flow conditions and plant power output outside the range covered by the calibration and verification? In our opinion such a model could provide reasonably valid information on the horizontal distribution of the vertically averaged

Dr. Robert L. Dwyer
December 5, 1984
Page three

excess temperature. However, this model could not provide any information concerning the vertical distribution of excess temperature, nor the horizontal distribution of excess temperature at any given depth. If there was even a moderate degree of vertical stratification, the dimensions of a given isotherm of excess temperature in the plume at the surface could be considerably larger than the dimensions of the corresponding vertically averaged isotherm.

One approach to extending the results of a vertically averaged model to an approximate three dimensional field is to use empirical relationships developed from observations of the vertical temperature structure under various plant loadings and river flows. The need to include observations at various river flows arises from the fact that the natural induced vertical stratification (as distinct from the stratification arising from the thermal discharge) depends on river flow. Use of the results from the laterally averaged model to guide and strengthen the empirical relationship would also be useful. The authors of the reports we reviewed did use such an abbreviated approach. However, they did not obtain data under various river flow conditions, and they lumped the data for various plant loadings together. Consequently, no relationship could be developed between vertical stratification in vicinity of the discharge and the two primary controlling parameters, plant loading and river flow. Thus, even if the vertical average model had been properly formulated, and had been driven at the open boundaries by data applicable to those boundaries, extrapolation of the empirically observed vertical stratification to conditions of higher plant load and higher river flow would still be suspect.

We trust this information sufficiently addresses your concerns.

Very truly yours,

Donald W. Pritchard

Donald W. Pritchard
Consultant

Harry H. Carter

Harry H. Carter
Consultant

DWP:HHC:eg
Attachment

We have two other questions on which we would like your advice (though not necessarily incorported into your reviews):

- In the dye study report, the simulations in Figs. 6.2, 6.4, and 6.6 were for summer conditions ($Q_R = 5m^3/s$; $Q_P = 45m^3/s$ and 660 MWE). The 1983 field data presented in the figures were for winter conditions ($Q_R = 32m^3/s$, $Q_P = 23.7m^3/s$; average plant load of 450-500 MWe, perhaps extrapolated by the unspecified method to 660 MWe). We are concerned that the hydrographic conditions in December 1983 were sufficiently different from the earlier conditions used in model calibrations to prevent extrapolation of results from one period to the other. Specifically, the high river flows in December ($>30m^3/s$) were accompanied by salinity stratification upstream of Chalk Point (a phenomenon not seen in any of the ANSP data used in model calibration). We are especially concerned that a model calibrated to completely mixed conditions will not be able to deal with a buoyant plume in a stratified water column (as implied by the comparison in Figs. 6.2, 6.4, and 6.6 in the dye study report).

- All of the field thermal and dye measurements used to calibrate and validate the model were made at less than full power (i.e., steady output of 660 MWe). Presuming the model was calibrated and validated correctly to those dates, could the model be used to predict the dimensions of the full-power plume? We are especially concerned about his methods of extrapolating thermal stratification at partial power to full-power predictions (see Ch. IV, p 424-434).

Please call me to discuss any of our comments, questions, or requested changes. We would like to have the revised documents back as soon after Thanksgiving as hummanly possible. I will call you on Monday, 26 November to see how you're doing.

We thank you again for your help.

Sincerely,

Bob

Robert L. Dwyer

RLD/gol

cc: F. Holland
J. Teitt, PPSP

APPENDIX B

REVIEW AND CRITIQUE OF PHYSICAL PROCESSES CONTROLLING THE TRANSPORT AND MIXING OF HEATED DISCHARGES FROM THE CHALK POINT STATION OF THE POTOMAC ELECTRIC POWER COMPANY AS CONTAINED IN 316 DEMONSTRATION DOCUMENTS.

By

D.R.F. Harleman

REVIEW AND CRITIQUE OF PHYSICAL PROCESSES CONTROLLING THE TRANSPORT AND MIXING OF HEATED DISCHARGES FROM THE CHALK POINT STATION OF THE POTOMAC ELECTRIC POWER COMPANY AS CONTAINED IN 316 DEMONSTRATION DOCUMENTS DATED SEPTEMBER 1983.

prepared for

Martin Marietta Environmental Systems
Columbia, Maryland

by

Donald R.F.Harleman
Consulting Engineer
Massachusetts Institute of Technology
Cambridge, Mass. 02139

November 1984

SUMMARY

The findings of the technical review of compliance with the State of Maryland's thermal discharge and mixing zone criteria for tidal waters are summarized in this section. The compliance question is summarized in two categories: dilution flow and plume dimensions. Justification for the summary statements are contained in the subsequent sections of the report.

DILUTION FLOW

The dilution flow requirement states that "the discharge flow may not exceed 20 percent of the annual average net flow past the point of discharge which is available for dilution". This statement contains ambiguities that are not capable of precise scientific definition. The ambiguities relate to the interpretation of (1) annual average "net" flow and (2) how much of this is "available" for dilution. When regulations are presented in this fashion, the applicant should not be faulted for interpretating them to his advantage. This reviewer will not make his own interpretation, rather he will confine his review to a technical assessment of the applicant's interpretation of this regulation.

- The computation of residual (non-tidal) circulation was carried out with a laterally averaged model (LAEM) covering the entire estuary. The ability of this model to generate realistic circulation patterns was seriously compromised by

limiting the calculations to stationary state conditions (tidal boundary conditions repetitive over many tidal cycles). The reviewer has provided examples of acceptable circulation studies that have been carried out in similar estuaries.

- The LAEM model was verified by comparing observed and predicted tidal ranges. This is not a valid test of the ability of the model to capture estuarine circulation patterns.

- The stationary state LAEM model predicted residual, non-tidal velocities that appear to be unreasonably high.

- Additional calculations of residual (non-tidal) flows were made with a vertically averaged model having a longitudinal extent in the estuary equivalent to about three tidal excursions. The verification of this model is inadequate because the ratios of observed to computed fluxes in the vicinity of Chalk Point do not show good agreement.

- A crucial point in the vertically averaged modelling effort, that was not addressed, is the question of how the longitudinal boundary conditions for the transport of dye and heat are treated. The reviewer has shown that the "effective dilution flows" calculated are incorrect because the model does not allow return of dye across the model boundaries.

- Additional calculations of estuary circulation were based on a simple two-layer analysis of salinity distributions measured during the December 1983 field survey. The salt balance model employed neglects vertical transport and diffusion of salt and is therefore of questionable value.

PLUME DIMENSIONS

The excess temperature plume dimension requirements are stated in terms of 24 hr. averages of the length and fractional cross-section of the plume.

- The plume dimensions, expressed as excess temperature, are derived from the vertically averaged model and the results are therefore subject to the criticism outlined above in regard to inappropriate model boundary conditions.

- The empirical surface area-excess temperature relationship used in the plume analysis was calibrated to the vertically averaged model results. The form of the equation is of questionable value for moving receiving waters. The comparison between the area-excess temperature relation and field data (1976-1979) does not generate any confidence in the predictive ability of the relationship. Therefore its use in determining plume dimension exceedance statistics is not justified.

- A linear dye-temperature correlation equation is used to analyze the December 1983 survey data for the purpose of determining ambient temperatures. The linear model assumes without justification that both dye and heat and conservative. The results are not significant in a statistical sense because of the low correlation coefficients (e.g. in the case of the plume length, only 19% of the variation is explained by the correlation equation.)

Recommendations

The general impression of this reviewer is that there has been far too much time and effort expended on model development and far too little on the direct use of the considerable amount of field data at hand. In general, the models used have not had the benefit of exposure and discussion that comes with publication in refereed journals. In addition, the modellers have not taken advantage of some of the excellent field data and earlier modeling studies by Pritchard and Carter on the Chalk Point Station (Refs. 8 and 9). These references discuss the analysis of dye and temperature data recognizing the non-conservative nature of the problem.

An example of the over reliance on models is the calibration of the emperical surface area-excess temperature relationship to the vertically averaged model. Subsequently, the calibrated model was compared to field data with poor results. The recommended procedure would be to calibrate and attempt to verify a surface area-excess temperature relationship directly with field data. In this regard all available field data, including the Pritchard-Carter data as well as the temperature data from the December 1983 survey should be used. It should be possible to develop emperical correlations among plume dimensions, plant MWe loading, fresh water discharge and ambient stratification by judicious analysis of the field data.

1. Introduction

The primary concern is with the question of compliance with the State of Maryland's regulations relevant to thermal mixing zone criteria. A number of documents related to the Chalk Point 316 demonstration provided by Martin Marietta were reviewed. The focus of this assessment is on the mathematical models documented in Ref. 1 and on the analysis of 1983 dye studies documented in Ref. 6.

The hydrodynamic and thermal modeling in Ref. 1 is based on two numerical models. The first, designated as LAEM, is a laterally averaged, two-dimensional, longitudinal-vertical, time-varying model intended to represent the overall circulation of the Patuxent estuary and the far field excess temperature distribution. The second is a vertically averaged, two-dimensional, longitudinal-lateral, time-varying model intended to represent the "more near field circulation conditions."

2. Laterally Averaged Model (LAEM)

The longitudinal-vertical model provides laterally averaged longitudinal and vertical velocity components and salinity and temperature distributions. The grid elements are 1 nautical mile long and 1 meter thick and extend 36 nautical miles from Cedar Point at the mouth of the Patuxent to Lyons Creek near the head of tide. The model is driven by a time-varying tide height and salinity profiles at Cedar Point and by freshwater inflow at the head of the estuary. An observed longitudinal salinity distribution is used as an initial condition. The LAEM model accounts for salinity (i.e., density) induced as well as tidally induced circulation.

It is stated on page 115 (ref. 1) that LAEM "has been applied to the Potomac River estuary and model results have compared favorably to tidal range, tide phase, intertidal velocity profiles and salinity distributions." However, a search of the references cited and other literature sources failed to uncover any documentation of a prior application of LAEM to the Potomac or any other estuary. (Appendix D of Ref. 1 refers to an unpublished report to the Corps of Engineers, Savannah River District, which this reviewer has not seen). The mathematical basis for LAEM is given in Appendix D of Ref. 1. However, no information is given on the formulation or magnitudes of the Reynolds stress coefficient (A_x), the longitudinal and vertical diffusion coefficients (D_x and D_z) or the important question of how the salinity boundary condition is treated at the estuary mouth. Numerical results are given in Appendix E of Ref. 1, but none of the parameters mentioned above are specified.

Simulation runs using LAEM are described on Page 116 (Ref. 1). It is stated that "it was decided to examine stationary state conditions where parameters are repetitive over many tidal cycles". In particular, the tidal range at Cedar Point was fixed and "the diurnal inequality and other longer-period tidal components were ignored". This reviewer is of the opinion that this limitation to <u>stationary state conditions</u> seriously compromises the ability to generate realistic estuarine circulations. The reasons for this opinion are stated in the following paragraphs.

It is well known that estuarine circulation is a result of complex, non-linear interactions between time-varying astronomical and meterorological forcing functions. Pritchard and Rives (Ref. 2) analysed synoptic lateral and vertical records from 22 current meters deployed over two cross-sections in Chesapeake Bay. The current meter records extended over 26 tidal cycles (approximately 13 days) and the distance between the two cross-sections was about 10 km. The non-tidal circulation for the 13 day averaging period, shown in Fig. 1, illustrates the classical two-layered estuarine flow pattern of net seaward flow in the surface layer and net landward flow in the bottom layer. The freshwater flow rate for this period was approximately 3000 m^3/s, thus the circulating flows within the layers are of the same order of magnitude. Pritchard and Rives also plotted daily average values of the longitudinal component of the non-tidal velocity for each day of the 17 through 29 October velocity measurement period. An inspection of these figures shows that, contrary to the situation for the 13-day averaging period, the non-tidal velocity distribution for the daily average frequently departs significantly from the classical two-layered estuarine flow pattern. There is also considerable day-to-day variation in the flow pattern. For example, on 17 October the upper layer seaward directed flow was considerably augmented as compared to the 13-day average, and the up-estuary directed flow was decreased. On 18 October the flow was everywhere (except for one observation point in Section G) directed up the Bay. On the next day the nontidal flow was everywhere directed seaward. On 22 October and again on 27 October the flow was predominantly directed seaward through both sections. On the remaining

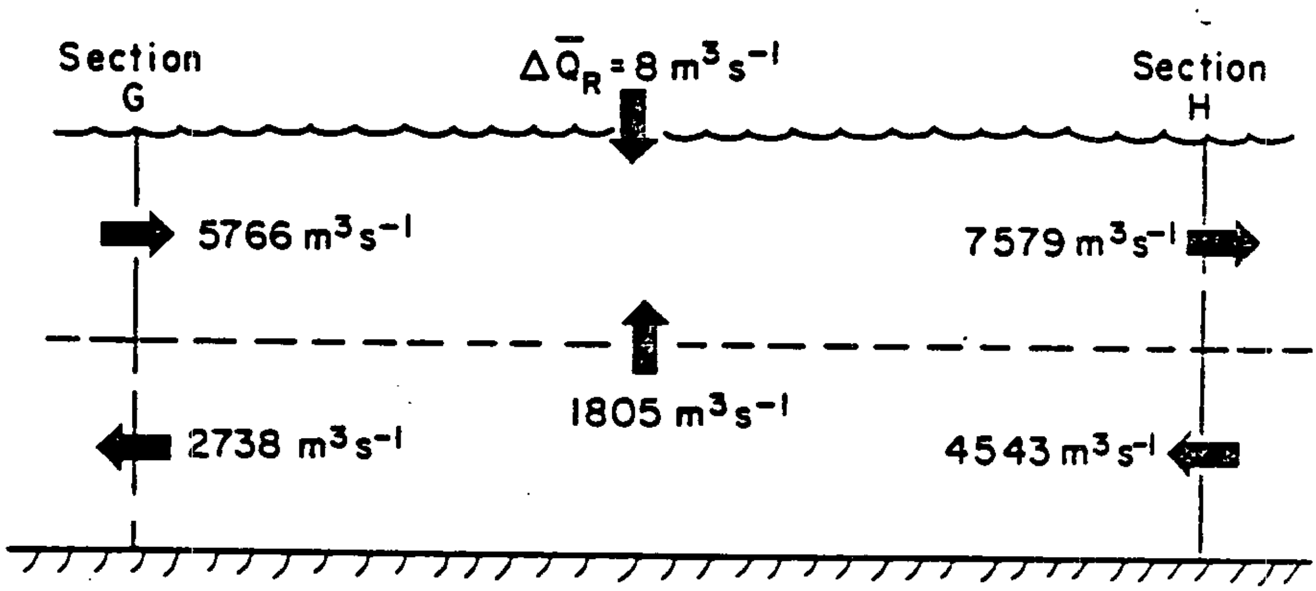

Fig. 1 Non-tidal circulation in Chesapeake Bay - 13 day averaging period. (Ref. 2)

days of the 13-day period the nontidal velocity distributions had at least the superficial appearance of a two-layered estuarine pattern. However, the relative intensities of the seaward directed flow and of the up-estuary directed flow varied significantly from day-to-day. The conclusion is that an averaging period extending at least through the spring-neap tidal cycle is necessary in order to capture the dynamics of estuarine circulation.

A number of laterally averaged numerical model studies of estuarine circulation and residual (non-tidal) longitudinal currents have been carried out in the Potomac estuary. Many of the characteristics of this estuary are similar to the Patuxent and certainly the methodologies employed are transferable. Wilson (Ref. 3) analysed synoptic current meter data at four stations in the Potomac for 8 tidal periods. Fig. 2(a) shows the observed laterally averaged residual currents and the classical two-layer structure is clearly evident. Fig. 2(b) shows the numerical model results and the agreement with the observed current profiles is striking. The vertical mean value of the residual current at all sections is of the order of .05 cm/sec. This corresponds to a freshwater discharge at the time of the observations of 425 m^3/s. In the range Pϕ-04 the residual ebb current in the upper layer is linear, ranging from zero at a depth of 5.5 m to 5 cm/sec at the surface. The estimated discharge in the upper layer is 950 m^3/s or about twice the freshwater flow rate.

Blumberg (Ref. 4) carried out a numerical model study on the Potomac in order to demonstrate the importance of the density variations (induced by the salinity gradients) on the vertical distribution of the residual

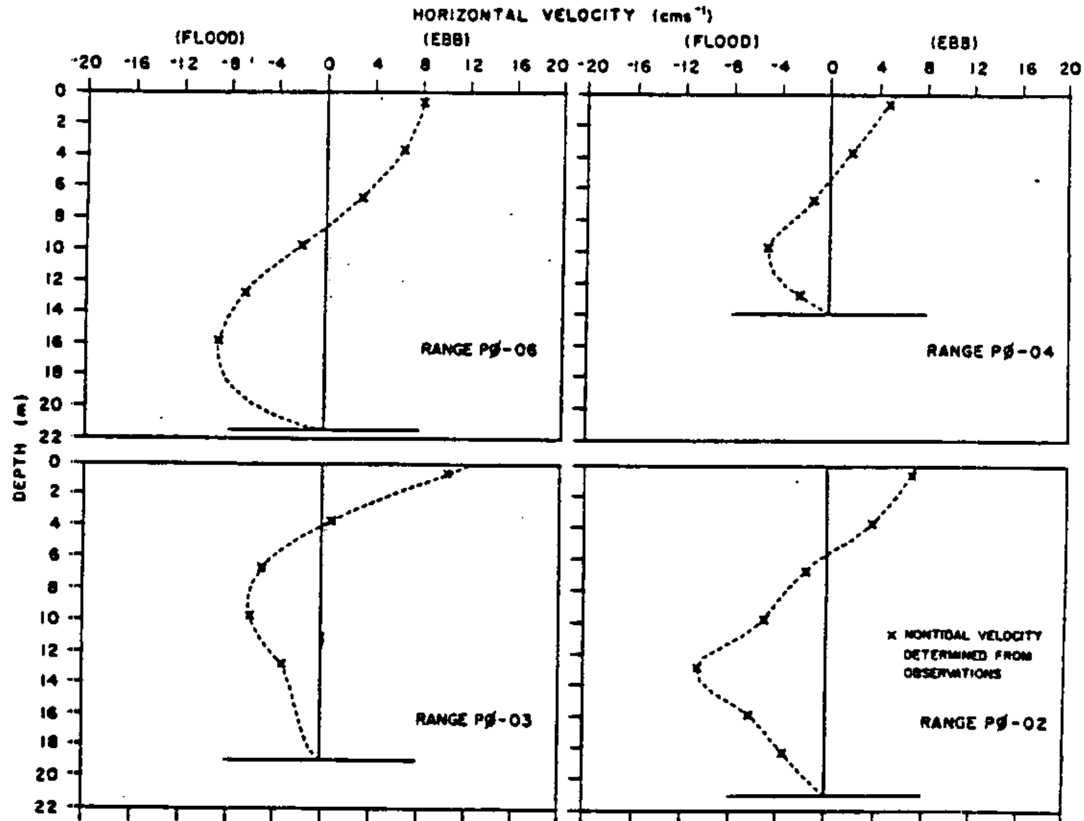

Fig. 2(a) Laterally averaged residual currents normal to the local channel cross section.

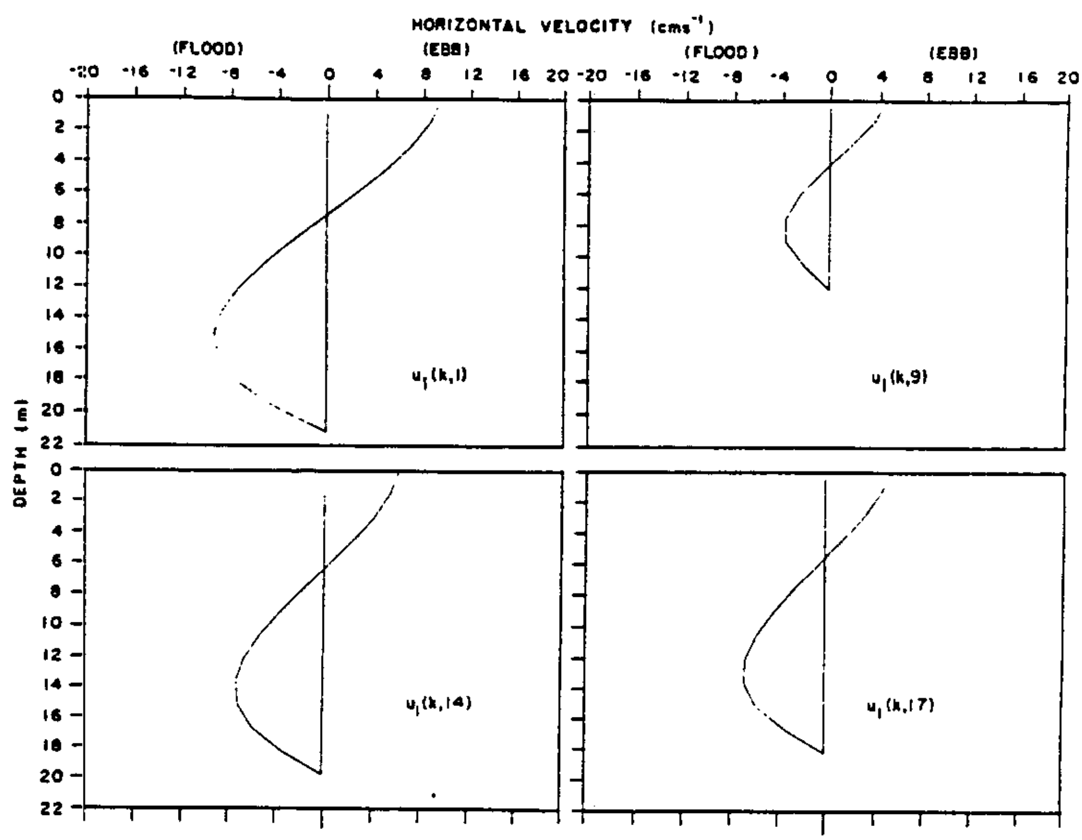

Fig. 2(b) Computed residual longitudinal currents $\mu_1(k, m)$ $(m = 1.9.14.17)$.

4 day averaging period
Potomac (Ref. 3)

velocity. His results, shown in Fig. 3, clearly indicate the importance of the density variations. Quantitatively Blumberg's residual current profile (including the density variation) is very close to Wilson's.

Wang and Kravitz (Ref. 5) devised a semi-implicit computational scheme for the laterally averaged model. The computational efficiency of this scheme makes it entirely feasible to carry out two-dimensional calculations for times of the order of a month so as to capture the long term effects on the residual current.

Having established the inadequacies of assuming "stationary state" conditions in the computation of estuarine circulation, it is appropriate to review the verification of LAEM as presented in Ref. 1. The tidally averaged circulation generated by the stationary state model is shown qualitatively in Fig. III-B, 2-1 of Ref. 1. It is not possible to calculate layer averaged flows as was done on the Potomac. The only verification presented for LAEM is a comparison of observed and predicted tidal ranges given in Table III-B, 2-8 of Ref. 1. The question of whether a comparison of tidal ranges is a valid verification of a two-dimensional circulation model has been answered conclusively and negatively by Blumberg (Ref. 4). Recalling Fig. 3 in which he demonstrated the drastic effect of density variations on the residual current profile, he shows in Table I that the minimum and maximum tidal amplitudes are similarly affected but that the tidal ranges were found to be identical (within 1%). It is concluded that the ability to reproduce tidal ranges is not a valid test of the ability of a model to capture an estuarine circulation pattern.

Given the lack of confidence in the quantitative features of the

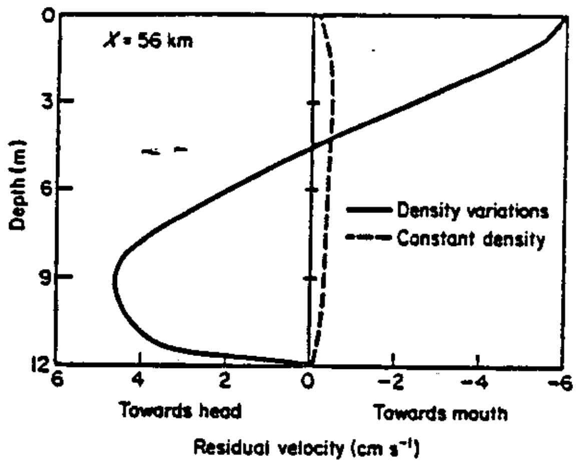

Figure 3. Comparison of tidally averaged vertical profiles of residual velocity at a station located 56 km from the mouth of the estuary. Potomac (Ref.4)

TABLE 1. Comparison of tidal properties*

$L/\Delta x$	Density variations			Constant density		
	η_{max}	η_{min}	Range	η_{max}	η_{min}	Range
5	21	−19	40	20	−20	40
10	23	−21	44	22	−22	44
15	23	−20	43	21	−22	43
20	24	−18	42	21	−22	43
25	23	−14	37	19	−19	38
30	28	−20	48	23	−25	48
35	34	−25	59	29	−31	60
40	46	−32	78	40	−38	78
45	55	−40	95	50	−45	95

*Tidal amplitudes (η) and range in cm. (Ref.4) circulation pattern computed by LAEM, it is difficult to have any confidence in the calculation of the vertically averaged excess temperature at the power plant discharge of 1.85° C (see p. 123, Ref. 1) and the associated dilution flow of 139 m^3/s. According to Table III-B, 2.1 of Ref. 1 the estimated freshwater flow at Chalk Point during the period July-August 1978 was about 14 m^3/sec. Thus, the so-called dilution flow is a factor of 10 larger than the freshwater flow rate and the ratio of dilution flow to freshwater flow for the Patuxent is considerably larger than the same ratio found in the Potomac and Chesapeake studies described above. Thus, the dilution flows found for the Patuxent appear to be unreasonably high.

3. Vertically Averaged Model

The analysis presented in Chapter IV of Ref. 1 is intended to provide information for the prediction of the spatial extent of the thermal mixing zone of the Chalk Point Station. In order to account for lateral, but not vertical variations, a two-dimensional, vertically averaged model is developed. For reasons not explained, this model extends only 6 km upstream and downstream of the Chalk Point Station. The total model length of 12.5 km is approximately 3 tidal excursions.

The vertically averaged model is driven by specified time and laterally varying tidal velocities at the upstream (Holland Cliff) and downstream boundaries (Long Point). One source of difficulty in this modeling effort is evident. Velocities in the field were actually measured at Benedict (2-1/2 km upstream of Long Point) and at Trueman

Point (3-1/2) km downstream of Holland Cliff). Thus, the distance between the measured velocity transects was only 6 km. It is stated (page 331 of Ref. 1) that velocity "values at Trueman Point were moved to Holland Cliff to extend the model as far upstream as possible." There is no justification for this arbitrary shift. It is however clear, as stated on page 312 of Ref. 1, that the time series current meter data were smoothed to a sinusoidal stationary state relationship in order to generate a repeating tidal condition.

The hydrodynamic and transport equations for the vertically averaged model are given on pages 322-323 of Ref. 1. Convective acceleration terms and density (buoyancy) effects are neglected in the momentum equations without explanation. No information is provided on the formulation or magnitude of the longitudinal and lateral dispersion coefficients D_x and D_y. As shown in Fig. IV-5 of Ref. 1, the model contains on average only 3 lateral grid elements. Thus, the results must be very sensitive to the conditions imposed on the longitudinal velocity at the lateral boundaries (e.g. slip or no-slip conditions). No information is given on the specification of the lateral boundary conditons for the longitudinal velocity.

Discussion of the verification of the vertically averaged model begins on p. 332 of Ref. 1 with a comparison of computed and observed discharges per unit width at Trueman Point, Chalk Point and Benedict (see Table IV-3, page 346 of Ref. 1). This reviewer does not understand the objectivity of comparing computed and observed fluxes at Trueman Point and Benedict. It is understood that the velocity boundary conditions used to drive the model were actually measured at these sections but then were arbitrarily transferred to the model boundaries at Holland Cliff and Long Point. It would appear that the only valid comparison is at Chalk Point which is approximately in the middle of the modeled estuary reach. The ratio of observed to computed fluxes on the West Bank at Chalk Point (1.8 at maximum ebb and 2.3 at maximum flood) does not show good agreement even though one would not expect the velocities in the middle of a 12.5 km reach to depart significantly from those imposed at the upstream and downstream boundaries.

The second model verification study (page 347 of Ref. 1) was based on comparisons with the 1979 field dye tests. The vertically averaged mass transport equation "was subjected to the same stationary-state flow field over many tidal cycles". The crucial point in this modeling effort which is not discussed in Ref. 1 is the question of how the boundary conditions for the transport of dye are treated. Since the upstream and downstream model boundaries are within a few tidal excursions of the station intake and discharge, the amount of dye within the model boundaries at any time must be very sensitive to the rate of return of dye across the boundaries. The dye comparisons in Fig. IV-16 of Ref. 1 show a high degree of underestimation of dye concentrations in the vicinity of the station discharge. It is significant that this section of the estuary is, as would be expected, the only one which displays a sizeable lateral dye concentration gradient. Similar problems exist in regard to the excess temperature verification shown in Fig. IV-18 on p. 361 of Ref. 1.

The procedure in Ref. 1 used for calculating the flushing rates and "effective dilution flows" is to assume an initially uniform concentration throughout the 12.5 km model reach. As tidal circulation and flushing take place, a continuous accounting of constituent in the model reach is made. The results of two model simulations for freshwater flow rates of 5 m^3/s (Fig. IV-24) and 86 m^3/s (Fig. IV-25) indicate that the mass of dye remaining in the reach follows a first order decay relationship

$$\frac{d}{dt}(M/M_o) = -k\left(\frac{M}{M_o}\right) \tag{1}$$

where M = the mass remaining in the reach, M_o = the initially uniform mass in the reach and k is a first order rate constant defined by EA as $k = \bar{Q}/\bar{V}$ where, $\bar{Q}$ = "effective dilution flow" and $\bar{V}$ = volume of water in the model reach (40.2×10^6 m^3). The solution to eq. (1) is the exponential relationship

$$M/M_o = e^{-kt} \tag{2}$$

and the values of k for the two fresh water flow rates simulated are $k = 0.684$/day for $Q_f = 5$ m^3/s and $k = 0.856$/day for $Q_f = 86$ m^3/s.

The procedure used in Ref. 1 for calculating the "effective dilution flow," $\bar{Q}$, from this model simulation is very simplistic. Equally simplistic is the fact that it can be shown that these dilution flows and their associated first order decay rates are a result of assuming that the volume of water entering the model reach on each tidal cycle is "new" water uncontaminated by dye. In other words, the model does not permit the return of dye across either of the model boundaries. This can be demonstrated by the following calculations which assume that the volume of "new" water for each tidal cycle is the sum of the tidal prism and the freshwater inflow:

Model reach length = 12.5 km
Model reach average width = 2 km
Average tidal range = 0.55 m

V_p = tidal prism for model reach

$V_p = (12{,}500)(2000)(0.55) = 13.8 \times 10^6\ m^3$

V_f = volume of freshwater inflow per tidal cycle

$V_f = Q_f \times T$, where Q_f = freshwater flow rate and
T = tidal period (44,640 sec.)

$V_f = 0.2$ z $10^6\ m^3$ for $Q_f = 5\ m^3/s$ and

$V_f = 3.8 \times 10^6\ m^3$ for $Q_f = 86\ m^3/s$

Thus, the total volume of "new" water entering the model reach on each tidal cycle is

$$V_n = V_p + V_f = (13.8 + 0.2) \times 10^6\ m^3 = 14.0 \times 10^6\ m^3$$
$$(\text{for } Q_f = 5\ m^3/s)$$

and,

$$V_n = V_p + V_f = (13.8 + 3.8) \times 10^6\ m^3 = 17.6 \times 10^6\ m^3$$
$$(\text{for } Q_f = 86\ m^3/s)$$

The "effective dilution flow", $\bar{Q}$, the total volume of "new" water per tidal cycle, is

$$\bar{Q} = \frac{14.0 \times 10^6}{44,640} = 314 \ m^3/s \qquad (\text{for } Q_f = 5 \ m^3/s)$$

and

$$\bar{Q} = \frac{17.6 \times 10^6}{44,640} = 394 \ m^3/s \qquad (\text{for } Q_f = 86 \ m^3/s)$$

The corresponding first order decay rates are

$$k = \frac{\bar{Q}}{\bar{V}} = \frac{(314)(86,400)}{40.2 \times 10^6} = 0.68/\text{day} \qquad (\text{for } Q_f = 5 \ m^3/s)$$

$$k = \frac{\bar{Q}}{\bar{V}} = \frac{(394)(86,400)}{40.2 \times 10^6} = 0.85/\text{day} \qquad (\text{for } Q_f = 86 \ m^3/s)$$

These k values are identical to the first order rate constants in Figures IV-24 and IV-25 of Ref. 1. The conclusion is that the effective dilution flows calculated in this section of Ref. 1 are incorrect because they evidently are a result of improper boundary conditions. From physical reasoning it is evident that a portion of the dye crossing the upstream or downstream boundaries must return to the model reach on successive flood or ebb tidal cycles. The consequence of the boundary conditions which do not allow return of dye is to increase the magnitude of the calculated "effective dilution flow".

4. Thermal Plume Analysis (Ref. 1)

The thermal plume analysis beginning on p. 370 of Ref. 1 has as its objective the calculation of the 24 hr. average thermal plume dimensions for full load (660 MWe) conditions in order to determine compliance with State regulations. A number of techniques were used to determine plume dimensions of area, length and cross-section. First, surface area-excess temperature relationships are derived from the two-dimensional, vertically-averaged model simulations for different plant loads and tidal conditions. A plume-scaling area relationship presented in Ref. 7 is calibrated by comparison with the model simulations. Second, the plume lengths and fraction cross-sections from the model simulations are related to plume areas. Third, the calibrated plume-scaling area relationship is compared with field data from the ANSP thermal plume surveys from 1976 and 1978-1979 to determine the variability of observed plume dimensions in relation to predicted plume dimensions.

A quantitative evaluation of the results of the plume analysis outlined above is impossible because of the model boundary condition problems identified in section 3. It must be assumed that the lack of dye return across the model boundaries applies equally to the question of heat return. Therefore, the excess temperature simulation runs are judged to be incorrect. However, a qualitative evaluation of the techniques used is presented in this section.

The first critique relates to the surface area-excess temperature relation (eq. 8, p. 374, Ref. 1)

$$A/A_n = (\theta/\theta_o)^{-n} (1 - \theta/\theta_o) \qquad (3)$$

where A is the surface area within the θ excess temperature contour, A_n is the scaling area expected to be a funciton of plant load, current speed, etc., n is an empirical parameter and θ_o is the plant discharge excess temperature (plant ΔT plus excess temperature at intake). In Ref. 7 a number of different excess temperature scaling relations are presented and discussed (i.e., Ref. 7, Ch. 5, equations 5.3.6 through 5.3.10). For example, a scaling relation in the form of eq. (3) is said to be appropriate to a jet discharging into deep stagnant water, whereas a relationship of the form

$$A/A_n = \left[\left(\frac{\theta_o}{\theta}\right)^p - \left(\frac{\theta_o}{\theta}\right)^q\right] \qquad (4)$$

where p and q are emperical exponents. Equation (4) is said to be appropriate to a surface jet into a moving ambient current. Ref. 1 gives no justification for choosing eq. (3) for application to Chalk Point where the ambient water is clearly not stagnant. The use of the area-temperature relation in the form of eq. (3) is further confused by uncertainty as to whether θ_o refers to the discharge temperature excess or to the excess temperature after near field jet dilution. (e.g. see Ref. 7, Ch. 8, equation 8.3.10 and Fig. 8.3.3). It would seem to be more reasonable for an emperical intermediate field area scaling relationship to be independent of changes in the near field jet dilution. Thus, the second interpretation of θ_o rather than the one used in Ref. 1 would be preferable.

The plume analysis of Ref. 1 continued with a calibration of eq. (3) to the vertically averaged model excess temperature simulation runs as shown in Fig. IV-28 of Ref. 1. The modelled plume dimensions (length and fractional cross-sectional area) are correlated to modelled plume area in Fig. IV-29. The next step is to compare the field data (1976, 1978, 1979 on plume area and dimensions with the calibrated form of eq. (3). The results presented in Figs. IV-31 and IV-32 of Ref. 1 do not generate any confidence in the predictive ability of the calibrated model. It is clear that the model does not capture the mean trend of the field data, therefore its use in generating plume dimension exceedance statistics (Fig. IV-33, Ref. 1) is not justified.

5. Compliance With State Regulations (as presented in Ref. 1)

The Code of Maryland Regulation (COMR) 10.50.01.13, E(1)(a) to E(1)(d), defines the boundaries of an allowable mixing zone in tidal waters in terms of a 2°C isotherm length, percent cross-sectional area and percent bottom area relative to the tidal excursion distance and limits discharge flow to "20 percent of the annual average net flow past the point of discharge which is available for dilution."

Ref. 1 addresses compliance with the above regulations by computing a "standard plume" (24 hr. average) based on the two-dimensional, vertically mixed model and the plume simulations discussed in sections 3 and 4 of this report (Fig. IV-44, Ref. 1). On the basis of the modelling inadequacies already discussed it is not possible to draw quantitative conclusions in regard to compliance, either in regard to plume dimensions or in regard to dilution flow.

6. Analysis of 1983 Dye Studies and Comparison to Model Results

Reference 6 presents the analysis of field measurements of dye and temperature made during 15 days in December 1983. The objectives of this study were to provide additional information 1) to characterize the estuary recirculation, 2) on the size of the thermal plume at full load and 3) to verify the previous (Ref. 1) hydrodynamic and thermal modeling results.

Net non-tidal circulation is addressed on pages 2-4 of Ref. 6 where a "simple two-layer analysis" of salinity distribution in the vicinity of Chalk Point is presented. The steady state salt balance equations (2.1 to 2.3) neglect the vertical transport and diffusion of salt. As shown in Fig. 1 of this report, this flux is generally an important part of the salt balance. The results of the simple analysis are therefore of questionable value. Additional calculations on net non-tidal circulation is presented on pages 3-5 of Ref. 6 where the decay of dye after shut down of dye injection is calculated following the methodology of Ref. 1 (see equation (2) of this report). This equation assumes that the entire modelled section from Holland Cliff to Long Point is spatially mixed at each time step. There is no evidence presented in Ref. 6 to support this assumption, nor is there any plot of data to support the decay rate of 0.358/day and the corresponding dilution flow of 167 m^3/s, which is seven times the plant pumping rate.

Section 4 of Ref. 6 analyses the dye and temperature field data for December 1983 in an effort to determine recirculation rates. A linear dye-temperature correlation equation

$$T = a + bC \qquad (5)$$

(where T is temperature, C is dye concentration, a is ambient temperature and b is the slope of excess temperature per unit concentration of dye) is assumed based on the condition that both dye and heat are conservative properties. No quantitative justification for this simplistic assumption is given. Plots of excess temperature were made by subtracting the ambient temperature determined as described above from the field temperatures. The 2°C isotherms were contoured to determine isotherm lengths and cross-sections. These plume dimensions were correlated with plant load and the resulting correlation equations (4.2 and 4.3 of Ref. 6) were used for projection of plume dimensions to full load conditions. A major problem with the results is the r^2 values for the correlations. In the case of plume length only 19% of the variation is explained by the correlation equation, while for percent cross-section only 30% is explained. These correlation equations are essentially meaningless in a statistical sense.

Section 6 of Ref. 6 presents comparisons of model results and re-evaluates compliance with state criteria. Because of the limitations of the data analysis discussed above it appears that the predictions based on the December 1983 field data have not increased confidence in the quantitative aspect of compliance over that presented in Ref. 1.

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APPENDIX C

LETTER REVIEWING AND CRITIQUING THE PHYSICAL PROCESSES CONTROLLING THE TRANSPORT AND MIXING OF HEATED DISCHARGES FROM THE CHALK POINT STATION OF THE POTOMAC ELECTRIC POWER COMPANY.

By

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28 August 1984

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Dear Fred,

I have completed my initial review of the report "Analysis of 1983 Dye Studies at Chalk Point Power Plant and Comparison to Model Results" by J. E. Edinger Associates, Inc. (EA). My major areas of concern are:

1. Estuary transport processes;
2. Comparison of survey results with model results;
3. Correlation of dye and temperature data;
4. Decomposition of dye;
5. Estimation of dilution of plant discharge.

ESTUARY TRANSPORT PROCESSES

Use of the model described on page 3-3 in EA's report for "decay of dye for a fully mixed segment of estuary" to estimate dilution flow is not appropriate. The factor "Q" in equation (3.1) is simply referred to as the dilution flow and a value of 167 cubic meters per second (m/s) was estimated by EA. The coefficient Q/V is estimated to be 0.358/day. At this rate approximately 70% of the tidal prism would be replaced with "new" water (water in the region for the first time) each tide.

Estimates by the Academy of Natural Sciences, Philadelphia (ANSP) in the "Chalk Point 316 Demonstration, 1983" estimated Q/V ratio to be 0.684 at a river discharge of 5 cubic m/s and 0.856 at 86 cubic m/s. These values would lead to the conclusion that between 140% and 170% of the tidal prism is replaced with new water each tidal period. These conclusions conflict with common sense. Further, they conflict with the results of the summer dye study conducted by Aquatec in 1979 and analyses of estuary transport discussed in the 1979 report.

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Both ANSP and EA apparently do not consider that regions of the estuary near the region of dye injection are initially untagged (contain no dye) and, at first, essentially untagged water returns during flood tide. As these adjacent regions become tagged, less untagged (or new) water returns and exchange rates apparently decrease. Return rates for a tracer injected into a estuary begin at values near zero and approach values near one.

This misrepresentation by ANSP and EA of estuary transport processes leads to incorrect conclusions of the amount of dilution water available to mix with the plant discharge and incorrect representation of conditions to describe mass transport at boundaries of models. The impact of over estimation of exchange processes on estimates of mass or energy (dye or excess heat) is less for highly non-conservative tracers and with boundaries far from the region of impact.

COMPARISON OF SURVEY RESULTS WITH PREDICTIONS

EA estimates of excess temperatures are referred to throughout the report as "observed excess temperatures." The values referred to are not observations; rather they are calculations, subject to serious errors when based on erroneous assumptions. Several assumptions employed in the regressions used in these calculations are well known to be false, i.e., that dye is conservative. In any case, reported results of excess temperatures are not "observed" and should not be given any credibility in excess of any other estimate of excess temperature without careful examination.

EA compares two "estimates" of excess temperature: one obtained from a winter survey and the other obtained from results of a model of summer conditions. Estimates of excess temperature by the ANSP were for low flow, warm ambient water temperature, and surface heat exchange characteristic of summer conditions. EA estimates were based on results of a survey conducted during the winter. Ambient water temperatures were lower during that survey and density gradients were less which results in less spreading of the plume. A temperature inversion at Long Point was measured demonstrating the gross difference between winter and summer conditions. River discharge in the winter survey varied and often was greater than 30 cubic m/s. No estimates of surface heat exchange in the winter were included in the report by EA to compare with the exchange rate used by ANSP in their mathematical model.

In my opinion, winter conditions are simply not similar enough to summer conditions to make direct comparisons.

CORRELATION OF DYE AND TEMPERATURE DATA

Although the analysis that relies on the regression of dye and temperature data is not sensible in view of the differences in the conservativeness of dye and excess heat, dye and temperature data should correlate well. An explanation for the generally poor correlation, only one of twelve correlations of dye and temperature had a coefficient of correlation greater than 0.9, was not given.

One possibility for the poor correlations could be that dye was injected at a nearly steady rate but excess heat varied. However, the summer 1979 survey conducted by Aquatec was also conducted with the plant operating with a variable load and of over 2500 regressions of dye and temperature, more than 1100 had coefficients greater that 0.9. Perhaps dye and temperature data were not taken with enough care to ensure high correlation of these data.

DECOMPOSITION OF DYE

Since decomposition of dye was not included by EA in their analysis of the survey results errors develop in estimates of excess temperature and exchange characteristics. Excess temperatures may in fact, for certain conditions, be over estimated. A mass balance of dye without properly describing decomposition would over estimate exchange characteristics and lead to erroneous conclusions on estuary transport.

ESTIMATES OF DILUTION OF PLANT DISCHARGE

Estimates of dilution using a ratio of estimated excess temperature/plant temperature increase obviously are erroneous since the excess temperature is the result of both surface heat exchange and dilution.

Dilution of plant discharge is achieved by mixing with river discharge. Circulation by density induced currents have no net transport; surface transport is balanced by bottom transport. Discharge into surface density currents may dilute a tracer and, if that tracer is sufficiently non-conservative, it may even dissipate before returning with bottom water; however, that does not appear to be the case at Chalk Point. At times, discharge water initially sinks and mixes with bottom water. In any case, it is not appropriate to estimate density induced volume flows using data obtained near Long Point and transfer the results to the region near the discharge which does not exhibit the same stratification.

I believe that, at a minimum, analyses of dye and excess temperature at Chalk Point must include mass balance for dye and energy balance for heat. Dye decomposes and plant heat is transferred to the atmosphere. The rates for these processes are different. The same hydrographic transport conditions must yield mass (dye) and energy (excess heat) balance before additional analyses are conducted.

If I can be of further assistance, do not hesitate to contact me.

Very truly yours,

Roger C. Binkerd

Roger C. Binkerd

RCB/crb